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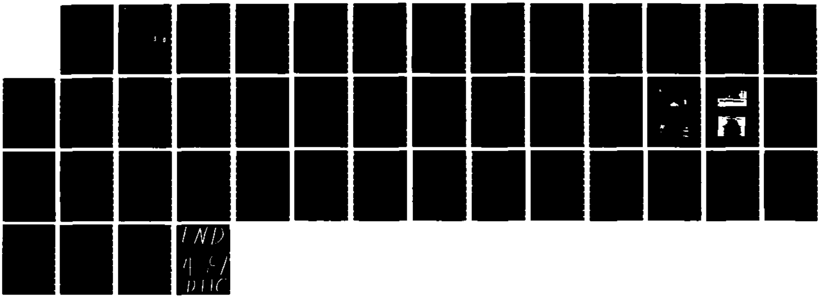

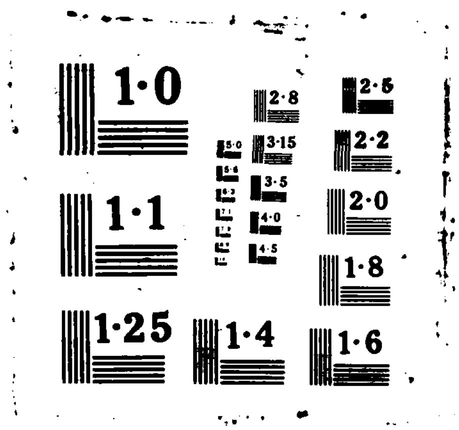
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USA-CERL TECHNICAL REPORT M-87/04
February 1987
Improved and New Roofing for Military Construction

Experimental Polyvinyl Chloride (PVC) Roofing: Field Test Results

by
Myer J. Rosenfield
James Wilcoski

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Results are reported for the first 2 years of a 10-year field test on three polyvinyl chloride (PVC) roofing systems. The test is part of long-term research by the U.S. Army Construction Engineering Research Laboratory (USA-CERL) to identify alternatives to conventional built-up roofing for military construction. The test roofs are installed on buildings at Chanute Air Force Base, IL, Dugway Proving Ground, UT, and Fort Polk, LA.

At the time of installation, the roofs were tested for initial properties to provide a basis for comparison with later samples. Test samples for each roof are taken at 6-month intervals and the sample section is patched. Properties evaluated are those considered essential to good roofing performance, they are tested using American Society for Testing and Materials (ASTM) standard methods in most cases. In addition, the roofs are inspected visually once each year.

Preliminary findings indicate that the PVC systems tested have remained relatively unchanged in terms of physical and mechanical properties. At this point, all roofs appear to be performing at a satisfactory level. Some characteristics, such as fungal growth, shrinkage, and streaking, will need careful scrutiny over the next few years to learn if they affect overall roof performance.

A Corps of Engineers Guide Specification (CEGS) has been developed based on these results. The CEGS allows the Army to specify, within limits, certain PVC roofing systems for military construction.

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At the time of installation, the roofs were tested for initial properties to provide a basis for comparison with later samples. Test samples of each roof are taken at 6-month intervals and the sample section is patched. Properties evaluated are those considered essential to good roofing performance; they are tested using American Society for Testing and Materials (ASTM) standard methods in most cases. In addition, the roofs are inspected visually once each year.

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A Corps of Engineers Guide Specification (CEGS) has been developed based on these results. The CEGS allows the Army to specify, within limits, certain PVC roofing systems for military construction. Keywords:

DISCLAIMER NOTICE

FOREWORD

This work was performed by the Engineering and Materials Division (EM) of the U.S. Army Construction Engineering Research Laboratory (USA-CERL) for the Directorate of Engineering and Construction, Headquarters, U.S. Army Corps of Engineers (HQUSACE) under Project 4A762731AT41, "Military Facilities Engineering Technology"; Task A, "Facilities Planning and Design"; Work Unit 044, "Improved and New Roofing for Military Construction." The HQUSACE Technical Monitor was Chester Kirk, DAEN-ZCF-B.

Appreciation is expressed to Chanute Air Force Base (AFB), IL, Dugway Proving Ground, UT, and Fort Polk, LA, for providing buildings and construction funds for the program and for taking periodic samples from the roofs, and to Bernard V. Jones and Vernon L. Kuehn of the U.S. Bureau of Reclamation for performing mechanical and physical tests on the material samples.

Dr. Robert Quattrone is Chief, USA-CERL-EM. COL Norman C. Hintz is Commander and Director of USA-CERL, and Dr. L.R. Shaffer is Technical Director.

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EXPERIMENTAL POLYVINYL CHLORIDE (PVC) ROOFING: FIELD TEST RESULTS

1 INTRODUCTION

Background

Most Army facilities use conventional roofing systems, such as built-up roofing (BUR), that are sometimes expensive and complicated to construct. These conventional roofing systems are often comparatively short-lived, resulting in high life-cycle roofing costs which are difficult for already overburdened Army operation and maintenance budgets to absorb. Therefore, Headquarters, U.S. Army Corps of Engineers (HQUSACE) has asked the U.S. Army Construction Engineering Research Laboratory (USA-CERL) to identify alternative, easy-to-install roofing systems that can improve the performance of Army roofing while reducing life-cycle costs. This project involves (1) evaluating innovative roofing systems and materials to determine alternatives to BUR systems, (2) providing a way to improve Army roof performance and reduce life-cycle costs, (3) improving contractor quality control (CQC) of BUR construction, and (4) developing or improving guide specifications for selected alternative systems.

Previous work has identified and evaluated alternative roofing systems that would be less susceptible to installation error or misapplication and would not be as sensitive to storage, handling, and weather considerations.[1] Three of these systems were selected for field evaluation in full-scale roof construction. These were the single-ply membranes of the ethylene-propylene-diene monomer (EPDM) and polyvinyl chloride (PVC) types, and the sprayed-in-place polyurethane foam (PUF) with an elastomeric coating. EPDM and PUF roofs were constructed in 1980[2] and the PVC roofs were completed during summer 1983.[3]

Objective

The objective of this report is to document the results to date of a 10-year field test program to evaluate PVC roofing systems.

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[1] E. Marvin, et al., *Evaluation of Alternative Reroofing Systems*, Interim Report M-263/ADA071578 (U.S. Army Construction Engineering Research Laboratory [USA-CERL], 1979); Myer J. Rosenfield, *An Evaluation of Polyvinyl Chloride (PVC) Single-Ply Membrane Roofing Systems*, Technical Report M-284/ADA097931 (USA-CERL, 1981); Myer J. Rosenfield, *Evaluation of Sprayed Polyurethane Foam Roofing and Protective Coatings*, Technical Report M-297/ADA109696 (USA-CERL, 1981).

[2] M. J. Rosenfield and D. E. Brotherson, *Construction of Experimental Roofing*, Technical Report M-298/ADA109595 (USA-CERL, 1981).

[3] Myer J. Rosenfield, *Construction of Experimental Polyvinyl Chloride (PVC) Roofing*, Technical Report M-343/ADA145406 (USA-CERL, 1984).

Approach

Field-testing of the PVC roofing involved the following procedures:

1. Roof systems were selected based on the findings in earlier USA-CERL studies.[4]

2. A test plan was developed using standard test methods published by the American Society for Testing and Materials (ASTM).

3. Test sites were selected.

4. Test guide specifications were developed.

5. Construction of the test roofing systems was monitored.

6. Test data were collected for 2 years after completion of construction.

7. Each roof was inspected visually once a year.

Mode of Technology Transfer

Information generated by this study was used in the development of Corps of Engineers Guide Specification (CEGS) 07555, *Polyvinyl Chloride (PVC) Roofing* (U.S. Army Corps of Engineers, June 1986).

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[4] E. Marvin, et al.

2 DESCRIPTION OF TEST PROGRAM

Construction of Test Roofs

PVC roof membranes were installed during FY83 at Chanute Air Force Base (AFB) in Rantoul, IL, Dugway Proving Ground, UT, and Fort Polk, near Leesville, LA. Products of three manufacturers were installed at each site over enough insulation to provide an overall R-value of 20 for each roofing system.

The systems at Chanute consist of a poured-in-place concrete deck, a two-ply organic felt and asphalt vapor retarder, and 2-1/2 in. of aluminum foil-faced isocyanurate foam board in two layers. Roofing systems were installed loose-laid and ballasted. Specific membrane materials were Plymouth Rubber Company's Plyroof PVC 45, USM Weather-Shield's Flexhide 45, and Sarnafil's G21 442. For the Sarnafil system, the top layer of insulation was faced with 3/4 in. perlite board, installed with the perlite up. The Plyroof system required a reinforced kraft paper slip sheet between it and the insulation. Figure 1* shows cross sections of the three systems.

Membrane materials at Dugway were Plymouth Rubber Company's Plyroof PVC 45 FR White, USM Weather-shield's Flexhide LR-50, and Sarnafil's G21 410. The systems consist of a poured-in-place concrete deck, 3 in. of aluminum foil-faced isocyanurate foam board in two layers mechanically fastened to the decks without a vapor retarder, a kraft paper slip sheet under the Plyroof membrane, and mechanically fastened Plyroof and Flexhide systems. The Sarnafil system was fully adhered. Figure 2 shows cross sections of the three systems.

The systems at Fort Polk consist of a tongue-and-groove wood plank deck and 4-1/2 in. of aluminum foil-faced expanded polystyrene insulation board in two layers which are mechanically fastened to the decks without a vapor retarder. Specific membrane materials were the same as those at Dugway Proving Ground. For the Sarnafil system, the top layer of insulation was faced with 1/2-in. fiberboard, installed with the fiberboard up. The Plyroof system required a reinforced kraft paper slip sheet, whereas the Flexhide system required a fiberglass slip sheet. No slip sheet was required by the Sarnafil system because of the fiberboard facer on the insulation. The Plyroof and Sarnafil systems were installed on an arched roof. Because of the curvature, the layers of insulation were fastened independently. The Sarnafil system was fully adhered. Figure 3 shows cross sections of the three systems.

Figures 4 through 6 show the buildings selected for these roofing systems at the three locations. Construction of these systems is described in detail in USA-CERL Technical Report M-343. In general, all roofs were easy to install and to repair after sampling. Since these test systems were installed, Plymouth Rubber Company and USM Weather-Shield have both ended production of roofing membrane materials. Difficulties encountered with the mechanically fastened systems were described in TR M-343 in which it was recommended that these systems not be used. The CEGS includes this recommendation.

*Figures and tables are located at the end of the report (see p 20).

Test Program

The test program was designed to determine how weathering would change the mechanical and physical characteristics of the various systems. Properties selected for study were those deemed essential to successful performance of the materials in a roof assembly. ASTM standard test procedures were used in the evaluation.

The initial set of tests was designed to establish the mechanical and physical characteristics of the materials at the time of application. Subsequent tests were scheduled at 6-month intervals for the first 2 years and then once a year for the next 8 years to establish a pattern of performance or to note changes in properties. A final test of field-exposed materials is proposed for 10 years after construction will have been completed. In addition to the laboratory tests, the roofs are being inspected visually once a year to check for changes in appearance, loss of adhesion of the fully adhered systems to their substrates, cracking, pinholing, and evidence of mechanical damage from foot or equipment traffic, unauthorized attachments or penetrations, or natural phenomena such as hail.

Table 1 lists characteristics of interest to this study. Original plans included continued testing for outdoor aging in Denver, CO, accelerated weathering, gas-chromatograph/mass spectrograph analysis, hardness, heat aging, plasticizer loss, dimensional stability, and water absorption; these tests were omitted due to a lack of funding.

3 PHYSICAL AND MECHANICAL PROPERTY CHANGES

Description of PVC Membrane Materials

Since the construction of the test systems, ASTM has published a specification that describes PVC membranes in three types, I, II, and III.[5] Type II is subdivided into two grades, for the following classification system:

Type I: Unreinforced sheet

Type II:
Grade 1 - Unreinforced sheet containing fibers
Grade 2 - Unreinforced sheet containing fabrics

Type III: Reinforced sheet containing fibers or fabrics.

On this basis, the materials used in the field tests are classified as shown in Table 2.

Besides the difference in membrane construction, the degree of polymerization of the vinyl chloride resin differs, as do the types and amounts of various plasticizers and processing oils used in the membranes' manufacture. Thus, the term "PVC" does not necessarily describe a single product, but more properly applies to a family of products. Exact types and proportions of the various ingredients are proprietary information, which is not released by the various manufacturers. Also, even the products of one company may differ from one time to the next, as the manufacturer changes formulations for economic, processing, or other reasons such as availability of materials. However, this difference between batches of the "same" product should not affect the properties of any specific material. Manufacturers are vitally concerned that their products are essentially the same at all times.

The important difference is between products of different manufacturers. As an example, one manufacturer of a PVC membrane recommends only ballasted installation of PVCs because its product is not resistant to ultraviolet (UV) light, and the ballast prevents this exposure. Another manufacturer does not recommend ballasted installation, because ballast tends to extract the plasticizers from its membrane, causing it to become brittle.

Initial Properties

Considering the above discussion, differences between the initial test values shown in Tables 3 through 5 are understandable. The values shown are averaged from several tests on the materials delivered to each location, according to the specific ASTM method used. Note that, in one case, the manufacturer and the test laboratory used different test methods for tensile strength. The manufacturer used ASTM D 412[6] whereas the test

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[5] ASTM D 4434, "Standard Specification for Poly (Vinyl Chloride) Sheet Roofing," *ASTM Annual Book of Standards* (American Society for Testing and Materials [ASTM], 1986).
[6] ASTM D 412, "Test Methods for Rubber Properties in Tension," *ASTM Annual Book of Standards* (ASTM, 1986).

laboratory used ASTM D 882.[7] Since the roofing material is not rubber and does not exhibit the same elastomeric behavior as does rubber, ASTM D 882 appeared better suited to the material than did ASTM D 412. In any case, the laboratory test results were higher than the manufacturer's values, which can safely be considered minimum ones. Although the published values claimed by Sarnafil are lower than the requirements of ASTM D 4434, the test values exceeded the specification requirements.

It must be noted that the manufacturers' data are based on materials produced long prior to the adoption of the ASTM document which, incidentally, requires a third basis for tensile property determination--ASTM D 638.[8] The Plyroof and unreinforced Flexhide membranes also exceeded the manufacturer's minimum values. After the adoption of ASTM D 4434, it was noted that they also exceeded the requirements in that standard.

Reinforced Flexhide samples from both Fort Polk and Dugway Proving Ground were sized too small to accommodate all the required tests, so a ply adhesion test was substituted for the breaking strength and elongation tests. Values for the Fort Polk material were 22 percent less than the manufacturer's published data. Initial Dugway samples were insufficiently sized for even this test, but the 6-month sample tested to a value almost 100 percent higher than the published data. (The consistency of results from this test over time is evident in Tables 10 and 11, which are discussed under **Property Changes** below.)

Plasticizer Loss

Although no data are available from Dugway due to inadequate samples, the differences between Chanute and Fort Polk data show a direct relationship between the behavior of membranes designed for ballasted application, as at Chanute, and those designed for exposure to the elements, as at Fort Polk. In all cases, the ballasted membranes showed a higher loss of plasticizer after 56 days than did the exposed ones. Membranes designed for exposure have to resist the tendency of UV and solar radiation to cause loss of plasticizer, whereas ballasted membranes are protected from sunlight by the ballast. PVC membranes tend to become brittle as plasticizers are lost.

Dimensional Stability

As might be expected, the unreinforced membrane (Plyroof at all three sites, Flexhide at Chanute only) showed a much greater change in length initially than did the reinforced ones. This phenomenon was discussed in the report on construction of these roofs,[9] and was also observed in service as noted in Chapter 4 of this report.

Water Absorption

Values for the Plyroof materials show that the exposed membrane at Fort Polk is more resistant to water than the ballasted membrane at Chanute. The significance of this finding depends on actual service conditions. Since the Plyroof at Fort Polk is installed on an arched roof, it is impossible for it to retain water in ponds.

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[7]ASTM D 882, "Test Methods for Tensile Properties of Thin Plastic Sheeting," *ASTM Annual Book of Standards* (ASTM, 1986).
[8]ASTM D 638, "Test Methods for Tensile Properties of Plastics," *ASTM Annual Book of Standards* (ASTM, 1986).
[9]USA-CERL Technical Report M-343.

The roof at Chanute, on the other hand, is ballasted and can retain moisture in contact with the membrane; moisture is absorbed by sediment that washes off the ballast and collects on the membrane surface. This sediment, which can stay wet for a long time, could conceivably cause the membrane not only to absorb water, but to retain it for long periods because the sediment could prevent the membrane from evaporative drying. However, no serious deterioration of properties has been apparent in the Plyroof membranes at either Fort Polk or Dugway Proving Ground where the same material has been installed, or at Chanute where the membrane is protected by ballast.

The Flexhide material at Polk can absorb considerably more water than the material at Chanute. Again, however, no serious deterioration of properties has been seen here or at Dugway, where the same material has been used.

The Sarnafil membranes exhibited essentially the same water absorption at both Chanute and Polk. These roofs also showed no serious deterioration of properties.

Property Changes

Results of the first 2 years of field testing are summarized below for some of the parameters tested. Properties of all three roofs have been fairly consistent over time. To see how the test results have changed for Plyroof, compare the data in Table 3 with those in Tables 6 through 8; for Flexhide, compare Table 4 with Tables 9 through 11; and for Sarnafil compare Table 5 with Tables 12 through 14. Additional property changes as observed in the visual inspections are described in Chapter 4.*

Thickness

All Plyroof membranes were listed by the manufacturer as being 45 mils thick and initial values were very close to these claims. The Fort Polk material was somewhat thicker than the other two initially. All three membranes have remained relatively unchanged with respect to thickness.

The Flexhide materials were nominally 45 mils at Chanute and 50 mils at Dugway and Fort Polk. Actual measured values are very close to these.

The Sarnafil membranes were all listed by the manufacturer as being 48 mils thick. The Chanute and Fort Polk materials were at or very close to this value, but the Dugway material was 14 percent thicker.

Laboratory tests on the samples taken at 6-month intervals have shown very little change in thickness for all three materials. In fact, the variations reported may be attributed to experimental error since differences are measured in a few thousandths of an inch. Moreover, the variations could be attributed to manufacturing tolerances, as samples could not be taken at the same location each time and thicknesses as

*An attempt was made to plot property changes so that trends could be visualized easily, but for some properties the scatter was too wide for the few points determined to enable reliable curves to be drawn. As stated previously, the important factor to be considered is the comparison of test values with manufacturers' claims. With the exception of the elongation of the unreinforced Flexhide at Chanute, measured property values exceeded those claimed or published by the manufacturers.

manufactured can vary from one location to another. For all practical purposes, the thicknesses have remained constant over the first 2 years.

Ply Adhesion

The Plyroof and Sarnafil membranes, being unreinforced, could not be tested for this property. Sarnafil may be considered as unreinforced for this property only. For other properties it behaves as a reinforced membrane. The Flexhide membrane, on the other hand, was supposedly the same product at both Dugway and Fort Polk, so the values from these two sites should have been close. However, ply adhesion at Dugway was much higher than that at Fort Polk initially and after 6, 12, and 18 months. At 24 months, the value at Fort Polk almost doubled (Table 11) but was still much lower than the average at Dugway Proving Ground.

The roof at Dugway exceeded the manufacturer's claim whereas the one at Fort Polk fell short of the 10 lb/in. width until the 24th month, when it surpassed this value. Because of the considerable sudden gain in value, this result can also be interpreted as an anomaly, and thus will have no significance. Further test results will show whether there has been a real change or if this result was an isolated phenomenon. If this value is treated as an anomaly, it could indicate inconsistency in manufacture since the value of the ply adhesion at Dugway tends to increase with time, whereas that at Polk remains essentially constant, and the actual numerical values at Dugway were consistently much higher than those at Polk as evident by comparing Tables 10 and 11.

Seam Strength

These values do not reflect initial conditions of the materials as much as they do the contractor's technique in assembling the sheets in the field. Each contractor was required to demonstrate the seaming technique before performing the work, but the demonstration seams were not tested immediately to establish their values. In any case, there are no established criteria at present for seam strengths. The Midwest Roofing Contractors Association (MRCA) has suggested that lap joints should develop 80 percent of the membrane's tensile strength.[10] Although the MRCA document does not say so, this criterion can only relate to the seam shear strength. Table 15 summarizes these values based on this method. Although not all seams achieved the recommended strengths, it is apparent that they are adequate to perform properly, as there have been no delaminations so far in any of the seams.

Accelerated Weathering

Table 16 shows the results of exposing samples of the membrane materials to accelerated weathering tests, both artificial[11] and natural.[12] Results of these tests indicate a wide variation in the materials' resistance to test conditions. Of all materials, the Sarnafil retained original properties best; the Flexhide and Plyroof samples were

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[10] *Recommended Performance Criteria for PVC Single-Ply Roof Membrane Systems*, Technical Document MP-10 (Midwest Roofing Contractors Association, November 1981).

[11] ASTM G 53, "Recommended Practice for Operating Light- and Water-Exposure Apparatus (Fluorescent UV-Condensation Type) for Exposure of Nonmetallic Materials," *ASTM Annual Book of Standards* (1984).

[12] ASTM E 838, "Practice for Performing Accelerated Outdoor Weathering Using Concentrated Natural Sunlight," *ASTM Annual Book of Standards* (1981).

affected to varying degrees. Table 17 rates the membranes on their gross appearance after the accelerated natural weathering tests.

Summary of Findings

Based on laboratory testing of the samples, the three PVC roofs are performing at a satisfactory level 2 years after installation. Findings from samples taken at 6-month intervals have been considered in writing CEGS 07555.

The PVC roofs at Chanute AFB, Dugway Proving Ground, and Fort Polk will be tested through FY93. Data gathered in these tests should provide a fairly clear picture of these roofs' performance under long-term exposure to the elements. Should any roof reach the point at which it can no longer be patched after sampling, the product will be considered to have failed and the roof will have to be replaced.

4 RESULTS OF VISUAL OBSERVATIONS

Each roof was inspected regularly as part of the evaluation process. At each inspection, the roof was checked carefully for visible signs of deterioration. Special attention was given to the patches where samples for testing had been removed as well as to flashings. Indications of need for maintenance or repair were recorded.

First Annual Inspections

After 1 year of service, all PVC roofs at Dugway Proving Ground were performing well. The Flexhide and Sarnafil membranes on both buildings were smooth and clean, but the Plyroof membrane, which was originally white, had become gray with what appeared to be dirt. Also, some PVC covers over the edge metal splices on the Plyroof section were splitting and had to be replaced. Patches where samples had been removed were applied in a neat, professional way. All wrinkles in the Plyroof membrane had disappeared due to shrinkage, and the membrane was now taut.

The membranes at Fort Polk from the same three manufacturers as those at Dugway were all in excellent condition. The Plyroof system, which was the only unreinforced membrane, originally had numerous wrinkles but these had all disappeared during the first year due to shrinkage. The Plyroof membrane was again the darkest, apparently from dirt. The Sarnafil membrane was fairly clean, and the Flexhide was in between the other two. Samples had been removed as specified and repairs were again done professionally. A white streak where all of the dirt was absent had appeared across the entire arch on the Plyroof membrane (Figure 7). The cause of this streak has not yet been determined. No apparent damage to the membrane was associated with this streak. The gutter along the west side of the arch was not straight with alternating low and high points, and one low point was leaking. Birds nesting above the Flexhide membrane were causing a high concentration of bird droppings to accumulate on this membrane. Thus, it will be possible to determine the effect of this phenomenon on a PVC roof by testing contaminated samples separately.

Second Annual Inspections

All three membranes at Dugway Proving Ground (Flexhide, Plyroof, and Sarnafil) were very dirty. Otherwise the membranes were still in very good condition after 2 years of service. Shrinkage of the Plyroof membrane had resulted in more wrinkling at the ends of the fastening bars and a tighter membrane than were evident the previous year.

The metal edging on the west sides of both buildings had been damaged by operations of a maintenance contractor. The PVC coating had been scraped off the gravel stop peak, exposing the bare metal. This area had to be repaired before it began to rust. On one building, the sixth seam from the chimney on the west side was slightly open and had to be sealed. The other building had a dried mass of light-green latex paint at the north end of the roof. This spot will need to be watched to see if it affects the Sarnafil membrane.

All three roofs at Fort Polk were still performing very well. What appeared to be dirt the previous year has now been established as fungus. This was clear because there was no growth along the copper-covered separation joint where rainwater running off the

copper washed the membrane and prevented growth of the fungus. A Plymouth Rubber Company representative looked at the roof and agreed that the discoloration was due to fungus. The fungus on all three roofs was much worse than the previous year, the Plyroof now being black. Even the Sarnafil membrane, unstained the previous year, had fungus.

The darkening of the membrane by fungal growth eventually will cause the membrane to lose its heat reflectance; thus, the roof will become very warm under intense sunlight and will no longer contribute to lower temperatures within the building.

The observed growth of fungus led to the inclusion of a fungus test requirement in CEGS 07555.

The fully adhered Sarnafil membrane had begun to separate from the insulation surface, indicating that the adhesive was losing its bonding ability. Six months later, Sarnafil sent an approved contractor to readhere the membrane. This work was done adequately but there were some workmanship problems in that some strips of patching should have been made wider.

After 2 years of service, all three roofs at Chanute AFB were doing very well with no observed problems. Ballast has protected the membrane from weather and fungal attack. All sample cuts were repaired in a neat, professional way. Plyroof and Flexhide, both being unreinforced, had shrunk and were now smooth and tight. Sarnafil, which contains reinforcing fibers, had neither shrunk nor stretched.

The shrinkage evident during these inspections was similar to that reported in Technical Report M-284, where it was noted that membranes had shrunk and pulled metal flashings up from their initial contact with the substrate. These findings were considered during development of CEGS 07555; accordingly, the CEGS prohibits the use of unreinforced membranes due to their tendency to shrink.

5 CONCLUSIONS AND RECOMMENDATIONS

The first 2 years' field test results indicate that PVC roofing is satisfactory for use by the Army in military construction. These roofs are easy to install; they also are easily repaired in case of damage, as was demonstrated by the frequent removal and patching of areas for testing.

Experience has shown that unreinforced membranes exhibit considerable shrinkage, both during installation and throughout the life of the roof. This property was considered during the development of CEGS 07555, which states that unreinforced membranes are not permitted.

Growth of fungus on the test roofs has produced two undesirable conditions: loss of esthetic appearance and loss of heat reflectance. This finding also was considered during development of the CEGS; that the material pass a fungal resistance test has been included.

Continued testing of these roofs until FY93 will provide a reasonably long-term history of the materials' behavior. Any problems with either the materials or the installation procedures should become evident before that time has expired.

Meanwhile, it is recommended that the Army proceed with the use of PVC as a roofing material, subject to the restrictions in CEGS 07555. Particular attention should be given to the last statement in Technical Note A of the CEGS, which requests that problems or benefits of the roofs be brought to the attention of Headquarters, U.S. Army Corps of Engineers (DAEN-ECE-S).

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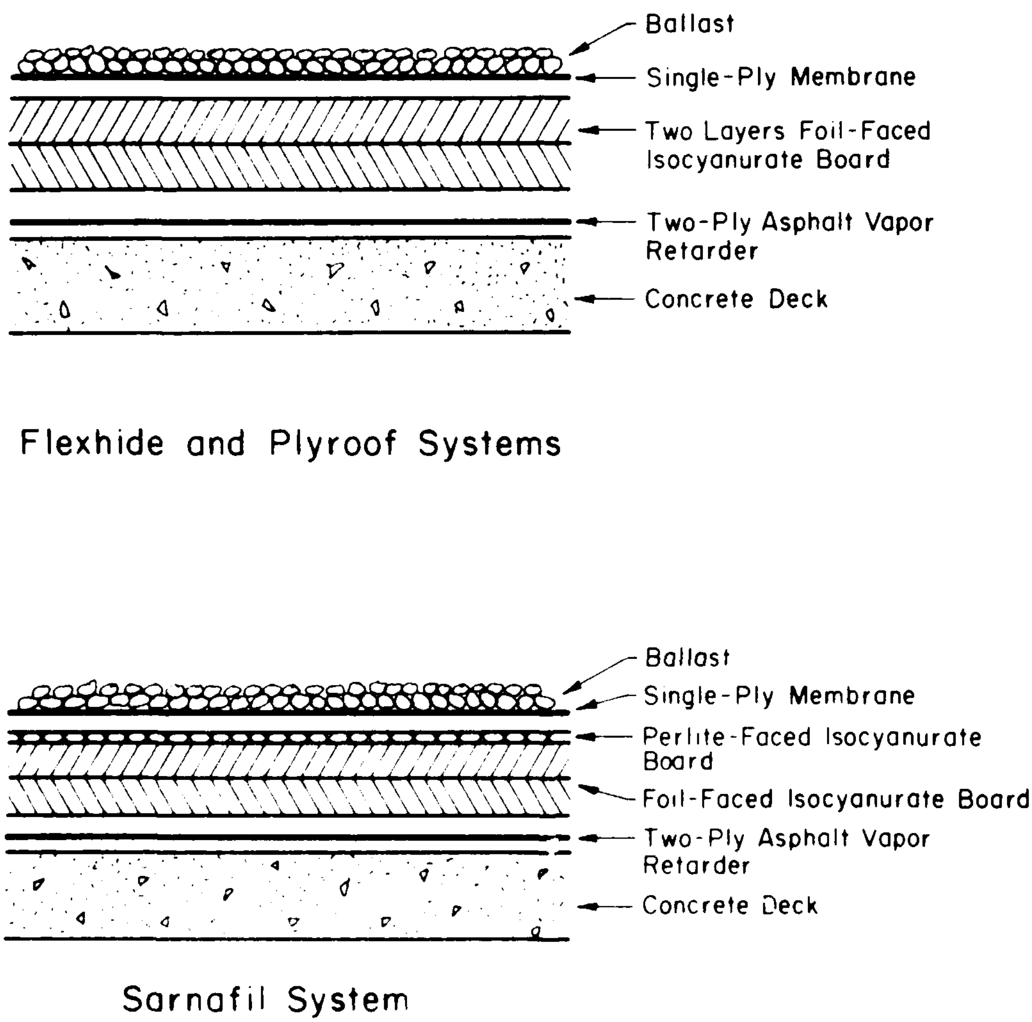
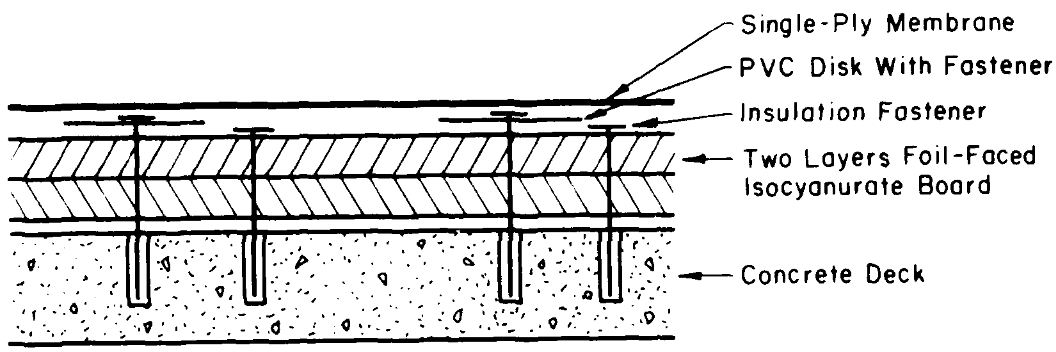
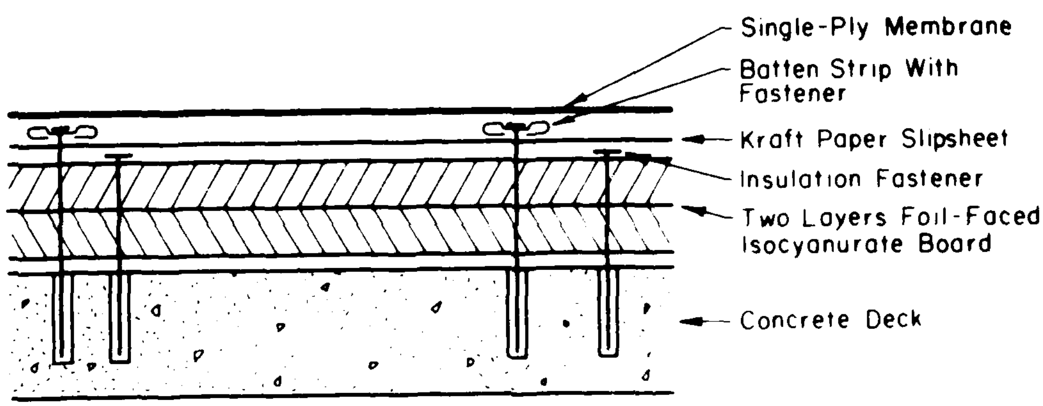


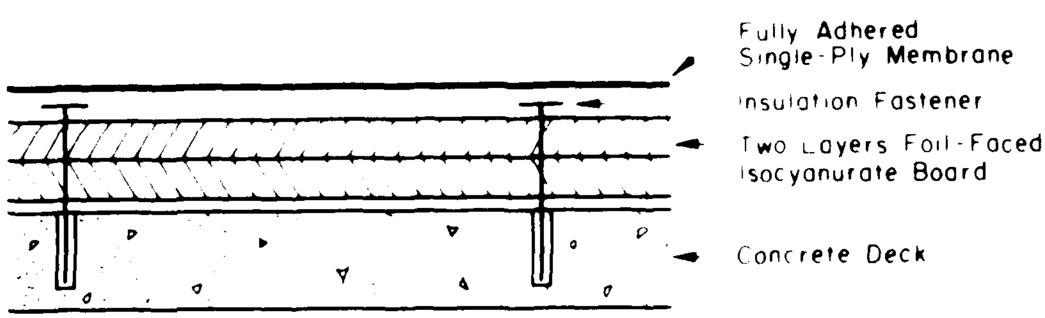
Figure 1. Roofing systems at Chanute AFB.



Flexhide System



Plyroof System



Sarnafil System

Figure 2. Roofing systems at Dugway Proving Ground.

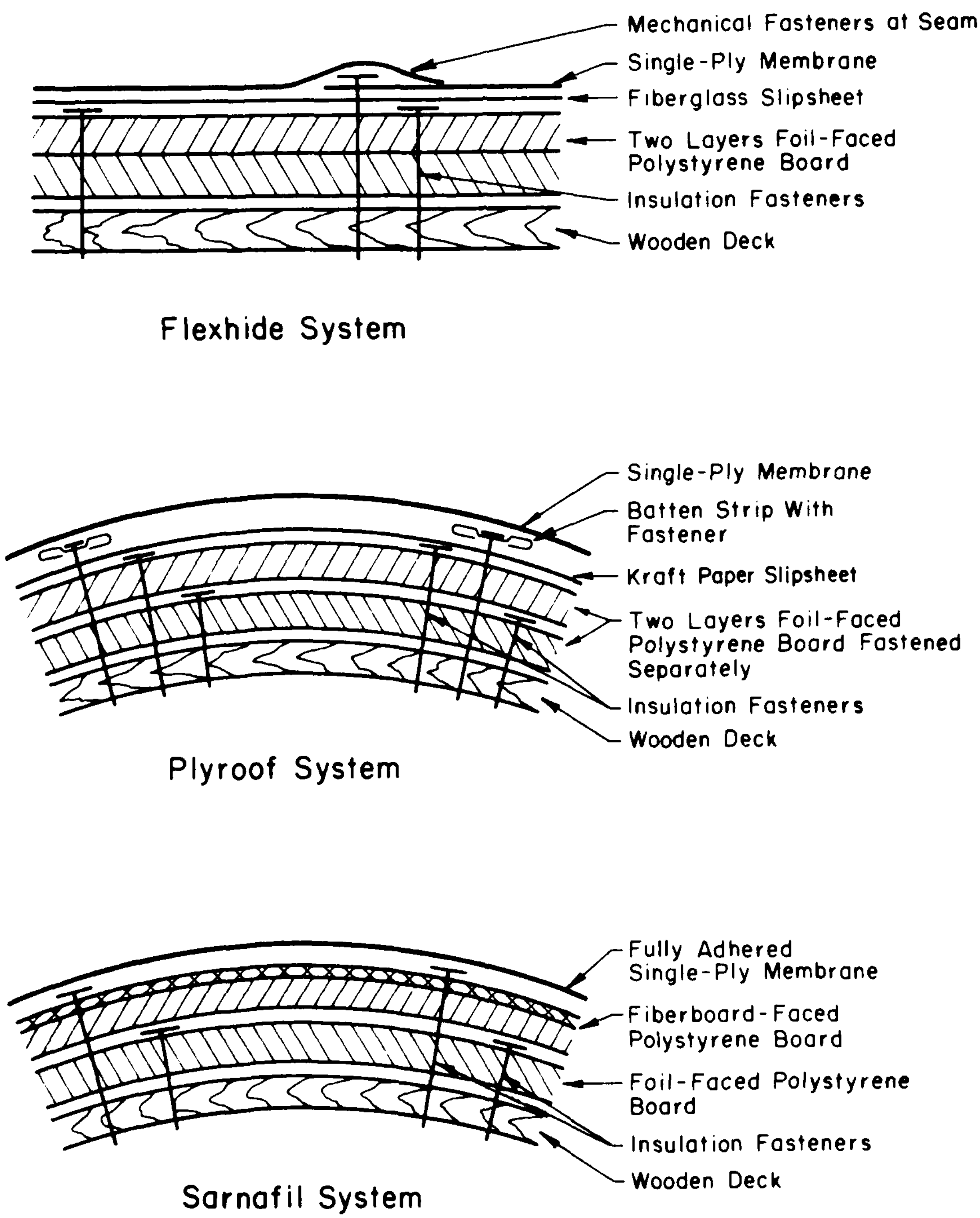


Figure 3. Roofing systems at Fort Polk.

Figure 4. Building selected for PVC roofing at Chanute AFB.

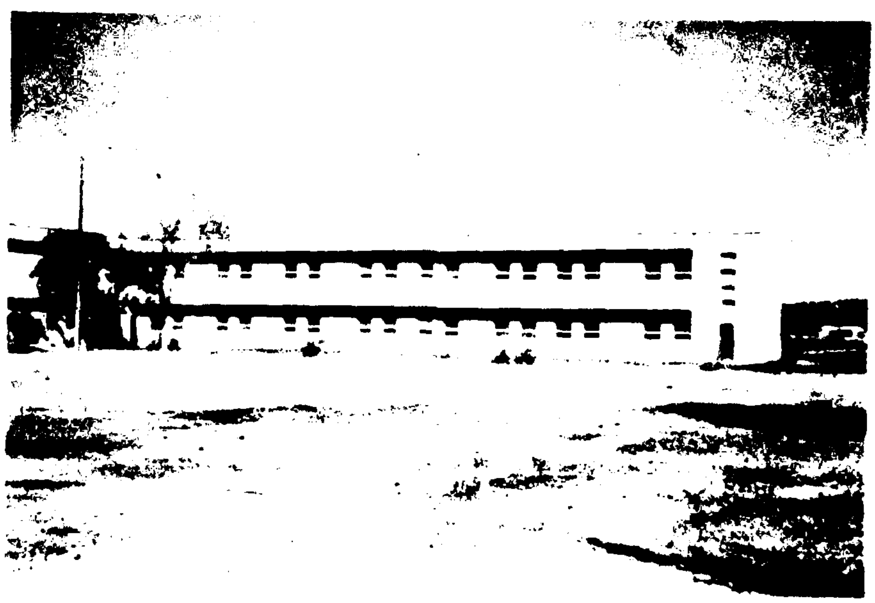


Figure 5. Building selected for PVC roofing at Dugway Proving Ground.

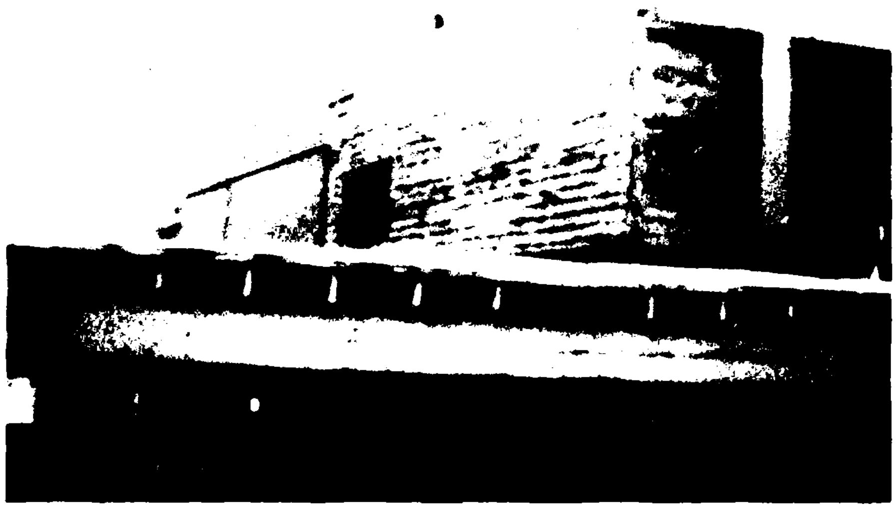


Figure 6. Building selected for PVC roofing at Fort Polk.

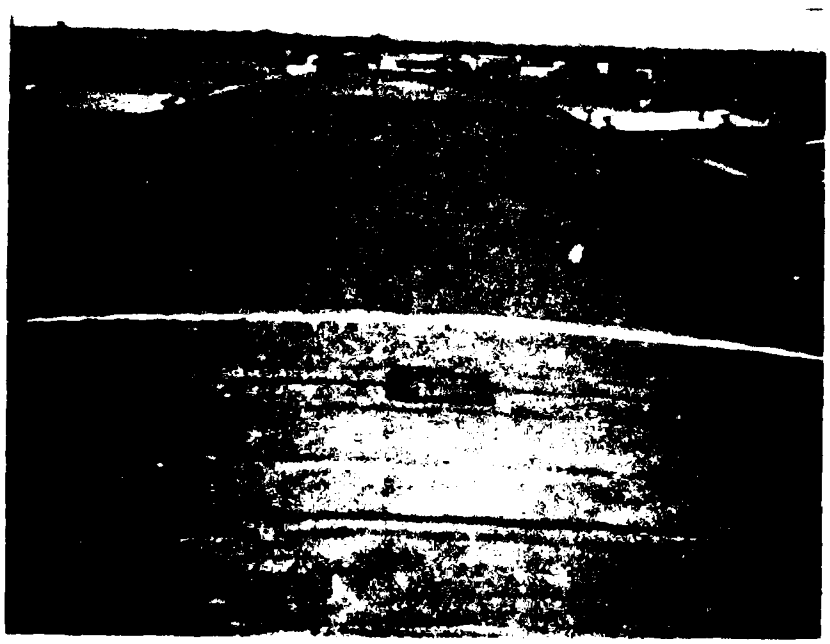


Figure 7. White streak across Plyroof membrane.

Table 1

PVC Test Characteristics

Property	Test Method	Remarks
1. Tests at beginning of exposure program		
Plasticizer loss*	ASTM D 1203	These tests enable predictions about weathering performance over the long term.
Dimensional stability**	ASTM D 1204	
Water absorption***	ASTM D 570	
2. Tests at beginning and intermittently during program		
Abrasion loss	ASTM D 3389	These are tests to establish the basic characteristics typical of roof membranes. Any changes in these characteristics during service would signal aging, deterioration, and reduced life expectancy. Abrasion resistance is necessary if the roof will experience regular foot traffic. Seam strength is essential in one-ply systems. Changes in tensile strength and elongation indicate a loss of plasticizer and resistance to mechanical damage. Changes in water vapor transmission also indicate loss of plasticizer.
Seam strength (peel)	ASTM D 1876	
Seam strength (shear)	ASTM D 882	
Specific gravity	ASTM D 792, A-1	
Tear resistance	ASTM D 1004	
Tensile strength	ASTM D 882, 751	
Elongation	ASTM D 882, 751	
Water vapor transmission	ASTM E 96,D	
Thickness	ASTM D 1593 ASTM D 751	

*Test conducted 56 days after installation.
**Test conducted for 6 hr at 80°C.
***Test conducted 52 weeks after installation.

Table 2

Classification of Roofs Used in Field Tests*

Brand Name	Test Site	Specific System	ASTM Classification
Plyroof	Chanute	PVC 45	Type I
	Dugway	PVC 45 FR	Type I
	Polk	PVC 45 FR	Type I
Flexhide	Chanute	Flexhide 4555	Type I
	Dugway	Flexhide LR-50	Type III
	Polk	Flexhide LR-50	Type III
Sarnafil	Chanute	G21 442	Type II, Grade 1
	Dugway	G21 410	Type II, Grade 1
	Polk	G21 410	Type II, Grade 1

*Based on ASTM D 4434, "Standard Specification for Poly(Vinyl Chloride) Sheet Roofing," *ASTM Annual Book of Standards* (1986).

Table 3

Initial Properties of Plyroof Membranes

Property	Manufacturer's Claim	Chanute AFB	Dugway PG	Fort Polk
Thickness, in.	0.045	0.047	0.048	0.046
Specific gravity	1.19*	1.27	1.33	1.31
Tensile strength, psi	2000			
Avg		2276	2083	2130
Range		2149 - 2319	1937 - 2292	2065 - 2196
Elongation, %	250			
Avg		290	260	256
Range		275 - 301	248 - 272	250 - 260
Tear resistance, lb	-			
Avg		12.8	12.6	11.6
Range		11.6 - 14.2	10.6 - 14.6	10.1 - 12.8
Seam strength, lb/in. width				
Peel	-			
Avg		21.9	13.7	13.5
Range		18.5 - 25.7	8.5 - 16.9	10.5 - 15.0
Shear	-			
Avg		74.5	82.3	79.8
Range		57.9 - 81.0	74.2 - 91.0	74.3 - 86.0
Vapor transmission perms	0.36**	0.24	0.26	0.27
Abrasion loss, g/2000 rev	-	0.02	0.03	0.02
Water absorption, weight %	-	2.2	***	1.6
Plasticizer loss, weight %	-			
Avg		7.7	***	4.4
Range		6.1 - 9.1		3.6 - 5.2
Dimensional stability, % change	3			
Avg		2.4	1.8	2.1
Range		2.3 - 2.5	(one sample)	2.0 - 2.2

*Or 0.28 lb/sq ft.

**Also $5g/24h/m^2$ from ASTM E 96A, which the manufacturer used instead of ASTM E 96D.

***Insufficient sample.

Table 4

Initial Properties of Flexhide Membranes

Property	Manufacturer's Claim: Chanute (Flexhide 45)	Manufacturer's Claim: Polk/Dugway (Flexhide LR-50)	Chanute AFB	Dugway PG	Fort Polk
Thickness, in.	0.045	0.050	0.045	0.050	0.049
Specific gravity	1.28	1.36 (0.30 psf)	1.27 (0.32 psf)	1.28	1.27
Tensile strength, psi	2330	-			
Avg			2467	*	*
Range			2200 - 2622		
Elongation, %	400	-			
Avg			269	*	*
Range			206 - 310		
Tear resistance, lb	-	100			
Avg			14.1	*	*
Range			12.6 - 15.3		
Seam strength, lb/in. width					
Peel			-		
Avg			44.4	40.6	19.8
Range			35.0 - 49.6	31.3 - 49.6	11.0 - 25.5
Shear	-		-		
Avg			80.4	149.4	116.3
Range			72.0 - 86.0	132.0 - 163.5	73.0 - 140.0
Vapor transmission perms	0.2	0.14		0.23	0.23*
Abrasion loss, g/2000 rev	-		0.01	0.01**	0.01
Water absorption, weight %	-		0.19	*	2.60
Plasticizer loss, weight %		-	-		
Avg		-	8.1	*	4.9
Range			7.0 - 9.0		4.4 - 5.3
Dimensional stability, % change	2	0.5			
Avg			2.4	0.4	0.4
Range			2.3 - 2.5	0.3 - 0.5	0.3 - 0.5
Ply adhesion, lb/in. width	-	10			
Avg			-	19.8**	7.8
Range				17.0 - 22.0	7.5 - 8.0

*Insufficient sample.
**Insufficient sample--6-month value used.

Table 5

Initial Properties of Sarnafil Membranes

Property	Manufacturer's Claim	Chanute AFB	Dugway PG	Fort Polk
Thickness, in.	0.048	0.046	0.056	0.048
Specific gravity	1.32 (0.33 psf)	1.25	*	1.27
Tensile strength, psi	1420 (ASTM D 412)			
Avg		1826	1482	1667
Range		1783 - 1891	1428 - 1536	1625 - 1708
Elongation, %	200			
Avg		254	253	232
Range		239 - 275	239 - 265	212 - 248
Tear resistance, lb	-			
Avg		15.7	15.8	16.1
Range		14.9 - 16.5	14.4 - 16.7	15.0 - 17.3
Seam strength, lb/in. width				
Peel	-			
Avg		47.8	*	50.8
Range		44.4 - 53.9		48.2 - 52.4
Shear	-			
Avg		76.1	74	77
Range		69.2 - 83	71 - 78	71 - 83
Vapor transmission perms	0.22**	0.24	*	0.25
Abrasion loss, g/2000 rev	-	0.01	0.01	0.01
Water absorption, weight %	-	0.84	*	0.99
Plasticizer loss, weight %	-			
Avg		4.3	*	1.8
Range		3.7 - 4.9		1.7 - 1.9
Dimensional stability, % change	0			
Avg		0.1	0.3	0.1
Range		0.0 - 0.3	0.3 - 0.3	0.0 - 0.3

*Insufficient sample.
**3 $g/24h/m^2$ from ASTM E 96A, which the manufacturer used instead of ASTM E 96 D.

Table 6

Aged Properties of Plyroof Membrane at Chanute AFB

Property	Age (Months) 6	12	18	24
Thickness, in.	*	0.047	0.047	0.045
Specific gravity	*	1.28	1.27	1.27
Tensile strength, psi				
Avg	*	2170	2234	2278
Range		2042 - 2276	2064 - 2468	2116 - 2433
Elongation, %				
Avg	*	274	284	278
Range		260 - 290	256 - 302	273 - 284
Tear resistance, lb				
Avg	*	12.9	13.8	13.6
Range		12.3 - 13.4	12.7 - 14.5	12.7 - 14.4
Seam strength, lb/in. width				
Peel				
Avg	*	**	**	33.5
Range				30.7 - 36.2
Shear				
Avg	*	74.8	**	78.9
Range		73 - 76.2		76.5 - 81.1
Vapor transmission perms	*	0.26	0.27	0.24
Abrasion loss, g/2000 rev	*	0.02	0.01	0.02

*No samples taken.
**Insufficient sample.

Table 7

Aged Properties of Plyroof Membrane at Dugway Proving Ground

Property	Age (Months) 6	12	18	24
Thickness, in.	0.045	0.048	0.047	0.048
Specific gravity	1.33	1.33	1.33	1.31
Tensile strength, psi				
Avg	2356	2146	2183	2131
Range	2222 - 2444	2062 - 2229	2087 - 2276	2042 - 2206
Elongation, %				
Avg	264	238	280	259
Range	255 - 278	222 - 255	270 - 289	251 - 275
Tear resistance, lb				
Avg	13.1	14.4	12.8	12.2
Range	12.7 - 13.8	13.6 - 16.0	11.7 - 14.9	11.5 - 13.1
Seam strength, lb/in. width				
Peel				
Avg	15.3	14.5	10.8	17.4
Range	3.2 - 32.0	10.5 - 19.0	4.6 - 15.1	9.5 - 31.0
Shear				
Avg	81.8	81.2	78.1	79.9
Range	73.0 - 90.5	76.5 - 85.0	74.3 - 84.0	77.3 - 84.0
Vapor transmission perms	0.28	0.27	0.25	0.24
Abrasion loss, g/2000 rev	0.03	0.04	0.04	0.08

Table 8

Aged Properties of Plyroof Membrane at Fort Polk

Property	Age (Months) 6	12	18	24
Thickness, in.	0.046	0.046	0.046	0.047
Specific gravity	*	1.36	1.32	1.32
Tensile strength, psi				
Avg	*	2174	2089	2096
Range		2065 - 2239	2000 - 2172	1996 - 2130
Elongation, %				
Avg	*	252	246	236
Range		238 - 260	240 - 250	138 - 239
Tear resistance, lb				
Avg	*	12.6	11.8	11.6
Range		12.3 - 13.1	10.7 - 13.0	10.6 - 12.3
Seam strength, lb/in. width				
Peel				
Avg	*	14.9	12.1	13.5
Range		10.1 - 19.2	7.8 - 18.1	12.5 - 14.3
Shear				
Avg	*	79.2	84.0	78.7
Range		74.3 - 83.0	81.0 - 88.0	78.8 - 83.4
Vapor transmission perms	*	0.26	0.26	0.26
Abrasion loss, g/2000 rev	0.01	0.01	0.01	0.03

*Insufficient sample.

Table 9

Aged Properties of Flexhide Membrane at Chanute AFB

Property	Age (Months) 6	12	18	24
Thickness, in.	*	0.046	0.045	0.045
Specific gravity	*	1.27	1.27	1.27
Tensile strength, psi				
Avg	*	2478	2600	2740
Range		2413 - 2761	2244 - 2758	2711 - 2753
Elongation, %				
Avg	*	250	250	265
Range		185 - 298	208 - 277	260 - 272
Tear resistance, lb				
Avg	*	14.0	15.8	14.1
Range		12.0 - 15.5	15.3 - 16.6	13.5 - 15.3
Seam strength, lb/in. width				
Peel				
Avg	*	28.5	36.0	35.0
Range		20.1 - 35.8	26.5 - 45.4	20.5 - 48.1
Shear				
Avg	*	92.2	87.6	84.4
Range		90.0 - 95.0	85.6 89.5	77.0 - 91.8
Vapor transmission perms	*	0.15	0.15	0.15
Abrasion loss, g/2000 rev	*	0.02	0.02	0.02

*No samples taken.

Table 10

Aged Properties of Flexhide Membrane at Dugway Proving Ground

Property	Age (Months) 6	12	18	24
Thickness, in.	0.05	0.049	0.05	0.048
Specific gravity	1.28	1.28	1.27	1.27
Ply adhesion, lb/in. width				
Avg	19.8	19.4	20.3	23.8
Range	17.0 - 22.0	17.0 - 23.0	19.5 - 21.0	22.5 - 25.0
Seam strength, lb/in. width				
Peel				
Avg	30.2	27.3	28.6	23.0
Range	17.0 - 22	24.0 - 31.5	15.0 - 43.9	19.8 - 26.3
Shear				
Avg	168	168	170	170
Range	162 - 171	162 - 175	164 - 175	149 - 184
Vapor transmission perms	0.23	0.23	0.21	0.21
Abrasion loss, g/2000 rev	0.01	0.02	0.02	0.03

Table 11

Aged Properties of Flexhide Membrane at Fort Polk

Property	Age (Months)			
	6	12	18	24
Thickness, in.	0.049	0.047	0.050	0.051
Specific gravity	*	1.27	1.27	1.27
Ply adhesion, lb/in. width				
Avg	7.3	7.7	7.9	14.9
Range	6.5 - 8.0	5.5 - 9.0	7.5 - 8.5	9.6 - 23.0
Seam strength, lb/in. width				
Peel				
Avg	20.2	22.2	25.0	30.6
Range	17.2 - - 22.6	15.5 - 31.4	16.4 - 33.4	25.9 - 37.9
Shear				
Avg	136	137	128	146
Range	130 - 144	120 - 166	88 - 170	126 - 155
Vapor transmission perms	*	0.27	0.22	0.24
Abrasion loss, g/2000 rev	0.01	0.02	0.02	0.02

*Insufficient sample.

Table 12

Aged Properties of Sarnafil Membrane at Chanute AFB

Property	Age (Months) 6	12	18	24
Thickness, in.	*	0.046	0.047	0.045
Specific gravity	*	1.25	1.26	1.26
Tensile strength, psi				
Avg	*	1913	1745	1938
Range		1804 - 1978	1680 - 1830	1844 - 1971
Elongation, %	*	252	212	223
Tear resistance, lb				
Avg	*	15.8	16.6	14.8
Range		14.4 - 17.5	15.3 - 18.1	13.9 - 15.9
Seam strength, lb/in. width				
Peel				
Avg	*	39.4	42.6	43.5
Range		30.1 - 44.3	36.0 - 49.1	36.4 - 50.4
Shear				
Avg	*	73.3	81.1	79.5
Range		68.0 - 80.0	69.0 - 85.6	76.0 - 81.0
Vapor transmission perms	*	0.27	0.26	0.25
Abrasion loss, g/2000 rev	*	0.01	0.01	0.01

*No sample taken.

Table 13

Aged Properties of Sarnafil Membrane at Dugway Proving Ground

Property	Age (Months) 6	12	18	24
Thickness, in.	0.054	0.054	0.054	0.049
Specific gravity	-	*	-	-
Tensile strength, psi				
Avg	1481	1444	1500	1633
Range	1426 - 1574	1407 - 1481	1417 - 1637	1549 - 1753
Elongation, %				
Avg	254	213	230	235
Range	241 - 267	200 - 220	217 - 253	203 - 260
Tear resistance, lb				
Avg	15.4	17.4	14.4	14.6
Range	14.6 - 16.9	16.7 - 18.5	12.6 - 15.3	13.2 - 15.6
Seam strength, lb/in. width				
Peel				
Avg	25.2	25.7	13.9	20.9
Range	7.5 - 42.0	13.5 - 36.5	5.0 - 23.2	10.3 - 35.3
Shear				
Avg	67.2	70.9	62.9	62.1
Range	56.0 - 80.0	61.5 - 75.2	50.5 - 73.7	53.6 - 70.6
Vapor transmission perms	*	*	*	*
Abrasion loss, g/2000 rev	0.01	0.05	0.04	0.09

*Insufficient sample.

Table 14

Aged Properties of Sarnafil Membrane at Fort Polk

	Age (Months)			
Property	6	12	18	24
Thickness, in.	0.048	0.052	0.049	0.049
Specific gravity	*	*	*	*
Tensile strength, psi				
Avg	*	1596	1694	1745
Range		1538 - 1635	1661 - 1751	1714 - 1778
Elongation, %				
Avg	*	231	223	226
Range		211 - 249	210 - 248	213 - 236
Tear resistance, lb				
Avg	*	17.1	14.7	14.2
Range		15.8 - 18.6	13.8 - 15.3	13.4 - 14.7
Seam strength, lb/in. width				
Peel				
Avg	*	44.6	46.6	50.8
Range		20.1 - 57.3	29.3 - 64.0	46.6 - 54.1
Shear				
Avg	*	79.2	77.3	74.1
Range		74.0 - 83.0	75.1 - 79.0	69.1 - 77.4
Vapor transmission perms	*	*	*	*
Abrasion loss, g/2000 rev	0.01	0.01	0.01	0.01

*No sample taken.

Table 15

Seam Strength Comparison

Membrane	Property	Chanute AFB	Dugway PG	Fort Polk
Plyroof	Tensile strength, psi	2276	2083	2130
	80% criterion	1820	1666	1700
	Seam strength, lb/in. (peel)	74.5	82.3	79.8
	Seam strength, psi (shear)	1520	1714	1735
	% of tensile strength	67	82	81
Flexhide	Tensile strength, psi	2467	--	--
	80% criterion	1970	--	--
	Seam strength, lb/in. (peel)	80.4	149.4	116.3
	Seam strength, psi (shear)	1785	2990	2370
	% of tensile strength	72	--	--
Sarnafil	Tensile strength, psi	1826	1482	1667
	80% criterion	1460	1185	1330
	Seam strength, lb/in. (peel)	76.1	74.0	77.0
	Seam strength, psi (shear)	1650	1320	1600
	% of tensile strength	90	89	96

Table 16

QUV and EMMAQUA Test Evaluations

Material Tested	Installation	Test*	Starting Date	Ending Date	Test Evaluation
Flexhide	Chanute	QUV	5-1-84	4-16-86	Darker color, stiffness, shrinkage, warping, and distortion
Plyroof	Chanute	QUV	5-1-84	4-16-86	Darker color, stiffness, warping, and distortion
Sarnafil	Chanute	QUV	5-1-84	4-16-86	Darker color, otherwise no change
Flexhide	Fort Polk	QUV	5-1-84	4-16-86	Darker color, stiffness, and distortion
Plyroof	Fort Polk	QUV	5-1-84	4-16-86	No change
Sarnafil	Fort Polk	QUV	5-1-84	4-16-86	No change
Flexhide	Dugway	QUV	5-1-84	4-16-86	Darker color, stiffness, and distortion
Plyroof	Dugway	QUV	5-1-84	4-16-86	Darker color, slight distortion
Sarnafil	Dugway	QUV	5-1-84	4-16-86	Darker color, otherwise no change
Flexhide	Chanute	EMMAQUA	5-15-84	2-14-85	Shrinkage, warping, distortion, and slight color change
Plyroof	Chanute	EMMAQUA	5-15-84	2-14-85	Shrinkage, warping, distortion, chalking, slight color, change, and slight checking
Sarnafil	Chanute	EMMAQUA	5-15-84	2-14-85	Good appearance, pinholes
Flexhide	Fort Polk	EMMAQUA	5-15-84	2-14-85	Slight warping and color change
Plyroof	Fort Polk	EMMAQUA	5-15-84	2-14-85	Slight shrinkage, pinholes, chalking, and slight color change
Sarnafil	Fort Polk	EMMAQUA	5-15-84	2-14-84	Good appearance
Flexhide	Dugway	EMMAQUA	5-15-84	2-14-85	Slight color change and warping
Plyroof	Dugway	EMMAQUA	5-15-84	2-14-85	Slight shrinkage, dark color change, and slight chalking
Sarnafil	Dugway	EMMAQUA	5-15-84	2-14-85	Good appearance, slight color change
Flexhide (Seam)	Chanute	EMMAQUA	5-15-84	2-14-85	Slight color change, shrinkage, warping, and distortion - good bond
Plyroof (Seam)	Chanute	EMMAQUA	5-15-84	2-14-85	Color change, shrinkage, warping, and distortion - good bond
Sarnafil (Seam)	Chanute	EMMAQUA	5-15-84	2-14-85	Good appearance, color change - good bond
Flexhide (Seam)	Fort Polk	EMMAQUA	5-15-84	2-14-85	Slight warping - good bond
Plyroof (Seam)	Fort Polk	EMMAQUA	5-15-84	2-14-85	Color change, chalking - good bond
Sarnafil (Seam)	Fort Polk	EMMAQUA	5-15-84	2-14-85	Good appearance - good bond
Plyroof (Seam)	Dugway	EMMAQUA	5-15-84	2-14-85	Good appearance - good bond
Flexhide (Seam)	Dugway	EMMAQUA	5-15-84	2-14-84	Slight warping and slight distortion - good bond
Sarnafil (Seam)	Dugway	EMMAQUA	5-15-84	2-14-84	Good appearance, slight color change

*QUV = ASTM G 53, "Recommended Practice for Operating Light- and Water-Exposure Apparatus (Fluorescent UV-Condensation Type) for Exposure of Nonmetallic Materials," *ASTM Annual Book of Standards* (1984). EMMAQUA = ASTM E 838, "Practice for Performing Accelerated Outdoor Weathering Using Concentrated Natural Sunlight," *ASTM Annual Book of Standards* (1981).

Table 17

Laboratory Rating as a Part of the EMMAQUA Test*

Roofing Material	Location	General Appearance	Color Change	Chalking	Checking/ Crazing	Cracking	Blistering
Flexhide	Chanute	8**	9	10	10	10	10
Plyroof	Chanute	8**	9	8	8	10	10
Sarnafil	Chanute	8***	8	9	10	10	10
Flexhide	Fort Polk	9**	9	10	10	10	10
Plyroof	Fort Polk	8***	8	9	10	10	8
Sarnafil	Fort Polk	9	9	10	10	10	10
Flexhide	Dugway	8**	8	10	10	10	10
Plyroof	Dugway	7	6	9	10	10	10
Sarnafil	Dugway	9	9	10	10	10	10

*Rating scale: 10 = as received; 9 = excellent; 8 = good; 7 = good to fair; 6 = fair; 5 = fair to poor; 4 = poor; 3 = poor to very poor; 2 = very poor; 1 = extremely poor.
**Warping was observed.
***Pinholes were observed.

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